

WE CLAIM:

1. A storage device, comprising:
 - a write head that encodes strands of molecular material with sequences of binary data;
 - a storage block for storing the strands;
 - 5 a read head for reading out a sequence of binary data from a selected strand; and
 - a transport mechanism that moves the strands between the read and write heads and the storage block.
2. The storage device of claim 1, wherein the strand includes a number of molecular bases that are encoded with the binary data, said read head detecting each base or collection of the bases within the strand to read out the binary data
5 directly from the strand.
3. The storage device of claim 2, wherein the read head comprises:
 - First and second chambers, which have a shared wall and contain a liquid,
 - 5 A nano-pore in the shared wall;
 - A voltage source that applies a voltage across said first and second chambers thereby producing an ionic current that flows through the nano-pore and pulling strands through the nano-pore as they are presented to the first chamber; and
 - 10 A current meter that measures fluctuations in the ionic current as each base or collection of bases in the strand flows through the nano-pore.
4. The storage device of claim 2, wherein the read head comprises:

A chamber that closely confines a strand as it moves therethrough, and

5 A microscopic probe held in close proximity to the passing strand such that the probe interacts with each base or collection of bases and produces a signal indicative of the binary data encoded therein.

5. The storage device of claim 4, wherein the microscopic probe comprises a scanning tunneling microscope tip that produces a tunneling current between each base or collection of bases and the tip.

6. The storage device of claim 4, wherein the microscopic probe comprises an atomic force microscope tip that deflects when held in close proximity to a base or collection of bases.

7. The storage device of claim 1, wherein said read and write heads and said storage block are integrated on a substrate, further comprising:

at least one reservoir of molecular material located off-
5 substrate that feeds molecular material to the write head; and
a dump located off-substrate for receiving the disposed strand.

8. The storage device of claim 1, wherein said read and write heads and said storage block are integrated on a substrate, further comprising:

at least one reservoir of molecular material located on
5 the substrate that feeds material to the write head; and
a recycle unit located on the substrate for receiving the disposed strand, breaking the strand into molecules, and returning them to the reservoir.

9. The storage device of claim 1, wherein the storage block comprises:

a plurality of parking lots for storing the strands;

5 a respective plurality of actuated gates that control the strands entrance to and exit from the respective parking lots and read and write heads, said actuated gates having unique addresses and being controlled by an external signal; and

10 a race track that is connected to the parking lots via the actuated gates and acts as a highway for transporting the strands.

10. The storage device of claim 1, wherein the write head receives blank strands and modifies the strands to encode the binary data.

11. The storage device of claim 1, wherein the write head receives distinct molecular bases and synthesizes them into strands to encode the binary data.

12. The storage device of claim 1, wherein the write head encodes the binary data into the base-sequence of the strand.

13. The storage device of claim 1, wherein the write head uses the strand as a support structure on which to encode the binary data.

14. The storage device of claims 11 and 12, wherein the molecular material includes at least two distinct bases, said write head comprising:

5 at least two reservoirs containing the different bases and a blocking group;

a main chamber coupled to the reservoirs by respective nano-pores;

an anchor in the main chamber for holding one end of a seed strand;

10 electrodes for applying a voltage between the main chamber and a selected reservoir to cause a free-floating end of the seed strand to enter the selected reservoir through its nano-pore where a single base and blocking group are added to the free-floating end of the seed strand and then to return to
15 the main chamber; and

a mechanism that removes the blocking group from the seed strand in the main chamber to prepare the strand for entry into the next reservoir.

15. The storage device of claims 11 and 12, wherein the molecular material includes at least two distinct bases, said write head comprising:

a tank partitioned into an upper chamber and a lower
5 chamber connected by a nano-pore, said chambers being filled with a buffer solution and said upper chamber containing enzymes for joining base units to a strand;

a chamber having at least two reservoirs containing different bases in a buffer solution, each reservoir having a
10 nano-pore at one end placed in the upper chamber of the tank;

a plurality of electrodes positioned in the upper and lower chambers and the at least two reservoirs to apply a series of electrical pulses that inject bases from their respective reservoirs into the upper chamber where they are
15 sequentially joined to the strand to encode the sequence of binary data and, once encoded, that transfer the strand to the lower chamber.

16. The storage device of claim 15, further comprising:

a monitoring station that senses the injection of a base into the upper chamber and closes the nano-pores so that only one base is joined to the strand at a time and senses the strand as it passes from the upper chamber through the nano-pore to the lower chamber to ensure that the strand represents the sequence of binary data.

17. The storage device of claims 10 and 12, wherein the blank strand comprises molecular bases having at least two states, the write head comprising:

an activator that transforms the bases into one of its states; and

a transport mechanism that pulls the strand past the activator to write the sequence of binary data into the strand.

18. The storage device of claim 17, wherein the blank strand comprises inert segments that separate the bases, the write head further comprising:

an exciser that removes the inert segments from the strand after the bases have been activated; and

a splicer that splices the active molecules back together into the strand.

19. The storage device of claims 10 and 13, wherein the write head comprises:

a first chamber having a strand of molecules and nanoparticles;

a second chamber having an access window, a chamber wall separating said first and second chambers having an ion-channel formed therein with the trans side of the wall being

chemically modified with surface attached photosensitizer groups capable of reducing the nano-particles;

10 a transport mechanism for pulling the strand and nano-particles through the ion-channel; and

15 a laser that emits pulses through the access window to excite the photosensitizers and activate reduction of the nano-particles to form nano-clusters bound to the strand at selected locations to encode the sequence of binary data.

20. The storage device of claim 19, wherein the nano-particles are Ag⁺ ions.

21. The storage device of claims 11 and 12, wherein the write head writes the binary data sequence into a strand using a ring-opening metathesis polymerization (ROMP) process.

24. The storage device of claim 1, further comprising a plurality of said read and write heads that address the storage block in parallel.

25. The storage device of claim 1, wherein the strands are electrically charged, said transport mechanism comprising a pair of electrodes that establish an electric field gradient that pull the strands around.

26. The storage device of claim 1, wherein the transport mechanism comprises a laser that forms optical tweezers that grab the strand and pull it around.

27. The storage device of claim 1, wherein the strands reside in a liquid, said transport mechanism comprising one or more micro-fluidic pumps that induce a flow current in the liquid

that moves the strand.

28. The storage device of claim 1, wherein the molecular material is DNA having bases of adenine (A), thymine (T), cytosine (C) and guanine (G).

29. The storage device of claim 28, further comprising a zip unit the forms a double-helix of the DNA strand for storage and an unzip unit that extracts the single strand for the read head.

30. The storage device of claim 1, wherein the molecular material is RNA having bases of adenine (A), uracil (U), cytosine (C) and guanine (G).

31. A storage device, comprising:

a plurality of parking lots for storing molecular strands;

5 a respective plurality of actuated gates that control the strands entrance to and exit from the respective parking lots, said actuated gates having unique addresses and being controlled by an external signal;

10 a race track that is connected to the parking lots via the actuated gates and acts as a highway for transporting molecular strands;

a transport mechanism that moves the molecular strands to and from the parking lots via the racetrack;

15 a write station that includes at least one inlet for receiving molecular bases, a write head that synthesizes the bases into strands in-situ to encode a particular binary sequence in a base-sequence of the strand, and an outlet connected to the racetrack; and

20 a read station that includes an inlet for receiving a strand from the racetrack, a read head for detecting bases or collections of bases in the strand to read out the binary sequence directly from the strand, and one or more outlets for disposing of the strand.

32. A storage device, comprising:

a patterned substrate having a network of liquid-filled canals; and

5 strands of molecular material encoded with a sequence of binary data in the liquid-filled canals and movable therein between different locations on the substrate.

33. The storage device of claim 32, further comprising:

a plurality of micro-fluidic valves that control access to the stored strands in addressable locations; and

5 a transport mechanism that moves the strands around in the liquid-filled canals.

34. The storage device of claim 33, wherein the strands are electrically charged, said transport mechanism comprising electrodes that establish an electric field gradient in the network of liquid-filled canals that pull the strands through
5 the canals.

35. The storage device of claim 33, wherein the transport mechanism comprises a laser that forms optical tweezers that grab the strands and pull them through the liquid.

36. The storage device of claim 33, wherein the transport mechanism comprises at least one micro-fluidic pump that induces a current in the liquid-filled canals that moves the

strands.

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37. The storage device of claim 32, further comprising a write station having an inlet for receiving molecular bases, a write head that synthesizes the bases into strands so that a particular sequence of binary data is encoded in a base-sequence of the strand, and an outlet that directs the strand into the network of liquid-filled canals.

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38. The storage device of claim 32, further comprising a write station having an inlet for receiving blank strands of molecular material, a write head that modifies the strand to encode a particular sequence of binary data in a base-sequence of the strand, and an outlet that directs the strand into the network of liquid-filled canals.

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39. The storage device of claim 32, wherein the strand comprises a number of bases or collections of bases encoded with the binary data, further comprising a read station that includes an inlet valve for receiving a strand from the liquid-filled canals, a read head for detecting each base or collection of bases to read out the binary sequence directly from the strand, and one or more outlets for disposing of the molecular material.

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40. The storage device of claim 33, wherein the micro-fluidic valves, comprise:

an inlet;

first and second outlets;

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a switch block; and

an actuator that moves the switch block back-and-forth to alternately block said first and second outlet.

41. A storage device, comprising:

a patterned substrate having a network of liquid-filled canals that define parking lots and a racetrack;

5 a write station that synthesizes distinct molecular bases in-situ into strands to encode a sequence of binary data in the base-sequence of the strand;

a read station that detects bases or collections of bases to read out the binary data sequence directly from the strand;

10 a plurality of micro-fluidic valves that control access to the parking lots and read and write stations in response to an external signal; and

a transport mechanism that moves the strands between the parking lots and the read and write stations via the network of liquid-filled canals.

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42. A method of fabricating a storage device, comprising:

Patterning a wafer to form ridges and canals that define a plurality of parking lots, a racetrack that interconnects the parking lots and to form chambers that define a read station and a write station;

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Processing the wafer using micro-fluidic fabrication technologies to define micro-fluidic valves in the canals that control access to and from the parking lots and the read and write stations;

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Filling the canals with liquid;

Fabricating a control wafer to define a plurality of addressing lines;

Mounting the control wafer on the wafer so that the addressing lines control the micro-fluidic valves; and

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Storing at least one strand of molecular material encoded with a sequence of binary data in the liquid-filled canal for

at least one said parking lot.

43. A method of storing and retrieving a sequence of binary data, comprising:

Writing in-situ a strand of molecular bases that represents a sequence of binary data;

5 Moving the strand to a memory address;

Storing the strand at the memory address;

Moving the strand from the memory address to a read location; and

10 Reading each base or collection of bases in the strand to determine an information unit of binary data.

44. The method of claim 43, wherein the step of writing the strand includes receiving a blank strand and modifying the strand to encode the binary data.

45. The method of claim 43, wherein the step of writing the strand includes receiving distinct molecular bases and synthesizing them into strands to encode the binary data.

46. The method of claim 43, wherein writing step encodes the binary data into the base-sequence of strand.

47.. The storage device of claim 43, wherein the writing step uses the strand as a support structure on which to encode the binary data.

48. The method of claims 45 and 46, wherein the strand of molecular bases is written by,

anchoring one end of a seed strand,

applying a voltage to cause a free-floating end of the

5 seed strand to enter through a nano-pore to a selected
reservoir where a single molecular base and blocking group are
added to the free-floating end of the seed strand;
extracting the strand from the reservoir; and
removing the blocking group from the seed strand to
10 prepare the strand for entry into the next reservoir.

49. The method of claims 45 and 46, wherein the strand is
written by,

storing different bases in a buffer solution in at least
two different reservoirs;

5 extracting a single base through nano-pores in the
reservoirs into a first chamber filled with buffer solution
and enzymes;

joining the base to grow a strand;

repeating the extraction and joiner until the strand is
10 encoded with the binary sequence of data; and

transferring the strand to a second chamber where it can
be moved to the memory address.

50. The method of claim 49, further comprising:

sensing the extraction of a base to close the nano-pores
so that only one base is joined to the strand at a time; and

sensing the strand as it passes from the first chamber
5 through a nano-pore to the second chamber to ensure that the
strand represents the sequence of binary data.

51. The method of claims 44 and 46, wherein the strand is
written by,

receiving a blank strand of bases, each base having at
least two possible states; and

5 selectively transforming the state of each base as the

strand is pulled past a write head to write the sequence of binary data into the strand.

52. The method of claim 51, wherein the bases are separated by inert segments in the blank strand, further comprising after all of the bases are transformed,

excising the inert segments from the strand; and

5 splicing the active molecules back together to reform the strand.

53. The method of claims 44 and 47, wherein the strand of molecules is written by,

chemically modifying the trans side of a chamber wall with surface attached photosensitizer groups capable of
5 reducing a certain nano-particle;

pulling a strand of molecules and the certain nano-particles through an ion-channel formed in a chamber wall; and

emitting laser to excite the photosensitizers and activate reduction of the nano-particles to form nano-clusters
10 bound to the strand at selected locations to encode the sequence of binary data.

54. The method of claims 45 and 46, wherein the strand of molecules is written using a ring-opening metathesis polymerization (ROMP) process.

55. The method of claim 43, wherein the strand is read by applying a voltage across a membrane having a nano-pore formed therein thereby creating an ionic current and pulling strands through the nano-pore thereby creating fluctuations in the

5 ionic current.

56. The method of claim 43, wherein the strand is read by passing it by a microscopic probe that detects the base or collection of bases.

57. The method of claim 43, wherein after the strand is read the strand is destroyed.

58. The method of claim 43, wherein after the strand is read the strand is broken into its constituent molecules and recycled.

59. The method of claim 43, wherein after the strand is read it is returned to the memory address.

60. The method of claim 43, wherein the strands are moved by, electrically charging the strands; and establishing an electric field gradient in the liquid-filled canals that pulls the strands around.

61. The method of claim 43, wherein the strands are moved by forming optical tweezers that grab the strands and pull them around.

62. The method of claim 43, wherein the strands are moved by pumping and thereby inducing a flow current in the liquid-filled canals that move the strands.

63. A method of fabricating a nano-pore in-situ for a read station in a storage device, comprising:

forming first and second chambers having a shared wall;

forming a hole in said shared wall; and

depositing nano-particles in the hole to shrink its size.

64. The method of claim 63, wherein the nano-particles are deposited using an electroless-plating process.

65. The method of claim 63, further comprising measuring an electric current through the shrinking hole and stopping deposition when the current reaches a certain value.